

Conference Paper



WIND ENERGY SYSTEMS FOR LEVELING RURAL ELECTRIC HEATING LOADS

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Abstract - Increased concern has been expressed by rural power suppliers about reducing peak electrical loads on rural power systems, particularly for heating and cooling loads that contribute substantially to electrical system peaks and affect energy costs through ratchet or other demand charges for wholesale power. Wind-energy applications for decreasing peak demands for electric heating loads are considered, and a preliminary analysis of experimental and simulation data for a 15-kW wind system is made.

I. INTRODUCTION

Renewed interest has been expressed in the wind as a source of power in the last 2-3 years, with greater emphasis in recent months because of projected increases in energy costs and prospects of energy shortages. Two percent of the solar energy reaching the earth is converted into wind energy, and the surface winds over the United States available for conversion are sufficient to supply about 30 times the total energy consumption of the United States (1). Main emphasis has been on a large-scale, commercial production of power through the use of wind generators with ratings of 100 kW or larger. Smaller 5- to 40-kW wind-electric systems installed on individual farmsteads, however, are a potential source of energy that should not be overlooked, both because of their ability to reduce consumption of nonrenewable energy resources and their potential for helping to reduce peak electrical loads on rural power systems.

Heating requirements of farmhouses are very similar to those of urban residences. Rural locations, however, allow the installation of alternative energy sources such as windmills more readily than do urban locations because of the availability of land and the decreased likelihood of problems with neighbors in relation to television interference, noise, or esthetics.

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Heating buildings now consumes approximately 10 percent of the energy used in agriculture. Of this amount, over 90 percent is used for the heating of farmhouses. Although the largest sources of heating energy are presently in the form of LP gas or oil, an increasing share of heating loads in rural areas is being met by electrical energy.

If nonrenewable energy sources continue to increase in price or are in short supply, electrical power will likely assume an even larger proportion of the heating load. If this increase in heating load is met by using resistance heating or electric furnaces with high peak electrical demands or by the use of heat pumps that operate during system peak demand periods, there will be substantial increases in peak loads on rural electrical distribution systems.

Wind energy can be used for heating farm buildings in several possible ways: (A) The wind system can be used to save nonrenewable energy resources such as oil or LP gas in a hybrid operation with existing conventional heat sources. The system would be sized so that its output rarely exceeded the heat load of the building and so that the heat supplied from the wind would be only a variation of the heat load carried by the existing system, and no storage would be used. (B) The wind system can be sized to carry a major portion of the heat load. Heat storage in a suitable medium such as water would be used to store energy that is in excess of immediate needs for use during the periods that the wind energy is not sufficient for the heat load and to serve as the heat source for the major portion of the load as currently is being done with many solar systems. The portion of the heat load that would be carried by conventional energy sources would depend on the incremental economic return of a larger wind system. (C) The wind system can be designed to carry the entire heat load, and the excess energy available above the nominal heating load used or converted for other purposes.

II. OBJECTIVES

The basic objectives of our USDA-SEA research project funded by DOE have been the development of both theoretical and empirical data on wind-energy applications for heating rural structures with wind-derived energy so that practical and economically feasible wind-energy systems can be designed and used to supply a portion of the rural-heating energy requirements, reduce consumption of nonrenewable energy resources, and decrease demand for electrical power during peak-load periods.

III. POWER AVAILABLE FROM THE WIND

The estimated energy from a wind-energy system may be determined from a knowledge of the probability density of the wind speed and the wind system characteristics in accordance with the following equation (2):

$$[1] \quad P_e = \int_0^{T_o} \left[\int_{V_{ci}}^{V_{co}} F(V) C_p(V)^{1/2} \rho V^3 A dV dt \right]$$

where P_e is the estimated power, T_o is the time period, $F(V)$ is the probability density of wind speed, C_p is the power coefficient of the wind system as a function of tip-speed ratio, V_{ci} is the cut-in speed, V_{co} is the cutout speed, ρ is the air density, V is the wind speed, and A is the swept area.

For a given time period, this becomes

$$[2] \quad P_e = T_o \int_{V_{ci}}^{V_{co}} F(V) C_p(V)^{1/2} \rho V^3 A dV$$

A typical wind-speed probability curve as determined from the U.S. Department of Commerce National Oceanic Atmospheric Administration (NOAA) data for Des Moines, Iowa, for 1975 is shown in Fig. 1 (3).

The average wind power for the winter in W/m^2 for 50 m above the earth is given in Fig. 2 (5). Although this is reduced at the nominal height of most small wind machines, these data give an indication of the substantial power available from the wind in large areas of the United States.

Although wind systems can differ substantially in their power output, depending on both their design and the wind regime in which they are used, it generally can be assumed that they will capture approximately 30-35 percent of the theoretical energy in the wind.

The wind system currently being tested in a USDA/DOE project at Bloomfield, Iowa, a Grumman Windstream 25*, is shown in Fig. 3. A simplified sketch of the heating system used with this wind system is shown in Fig. 4.

* Trade and company names used in this paper are solely for providing specific information. Their mention does not constitute a guarantee of their products or an endorsement over other products not mentioned.

The characteristics of this wind system of 15-kW capacity are given by the following equations:

$$\begin{aligned}
 P &= 0, V \leq 3.6 \\
 &= 1.89 - 1.27V + 21V^2, 3.6 < V \leq 11.6 \\
 &= 15, 11.6 < V \leq 26.8 \\
 &= 0, 26.8 < V
 \end{aligned}$$

where P is the power output in kW,
V is the hub-height wind velocity in m/s.

IV. STRUCTURE HEATING

The heating load of a typical rural structure will vary widely, depending on the basic design and insulation. For the purposes of this study, a simulation of wind-system performance and heat load have been made by using NOAA weather records for Burlington, Iowa, for the major heating months of December 1977 to February 1978. A moderately well-insulated structure with an area of 140 m² and a design heat loss 100 watts/m² at an inside temperature of 18°C and an outside design temperature of -29°C has been assumed. These results are shown in Table 1 for the Grumman unit described for a hub height of 12.2 m.

TABLE 1. Heat load and simulated wind system performance of the Grumman Windstream 25 for Burlington, Iowa, Dec. 1977 to Feb. 1978, with use of NOAA data for a 140 m² structure with a heat loss of 100 W/m² at an inside temperature 18°C and an outside temperature of -29°C.

Month	Average wind speed m/s	Structure heat load kW	Wind System Power		Structure Heat Load Supplied from Wind System %
			Average kW	Total kWh	
Dec. 77	5.95	4912	2.97	2212	45
Jan. 78	5.79	6189	3.04	2263	37
Feb. 78	4.72	5293	1.56	1052	20

For example, these data indicate that, for the month of January 1978, the total heat load for the period is 6189 kWh, or an average of about 200 kWh/day. The wind energy available for heating during this same period is 2263 kWh, or 37 percent of the total heating load. The required backup energy is 3926 kWh, or an average of 127 kWh/day. Data for the months of December and February show that wind energy can supply 45 and 20 percent, respectively. The average heating load that could be supplied by wind energy from the 15-kW wind system for the 3-month period is, therefore, 34 percent of the total heat load.

The heat load and wind system output for the 3-hour data for each day of January are given in Fig. 5 showing the wide variation in wind-system output with a maximum of 15 kW and an average of 3 kW.

Because of the large variation in energy output, a wind energy system used for heating generally is not cost effective unless some method of energy storage is used for the periods when the energy output of the wind system exceeds the energy required for the heat load. Water storage is an effective and relatively inexpensive method of providing this need. When the wind energy exceeds the heating load demand, the excess energy is stored in the water-storage system. A water-storage capacity of 4 m³ and a temperature rise of 20°C will allow an energy storage of 93 kWh. If this same storage is allowed to rise 50°C, the energy storage capacity will be 232 kWh. This size of storage and amount of energy would supply the heat load of the structure for about one average day in January.

V. LOAD LEVELING

Utility-system demand curves for an average load period and a peak load period are shown in Fig. 6 (4). Heating loads that add to this demand from 10 a.m. to 10 p.m. are highly undesirable. If heating loads can be minimized during these peak load hours or deferred to the offpeak period, the load factor (average load/peak load) can be greatly improved. Load factor is becoming an important factor in power generation and distribution as a measure of effectiveness of using electrical power facilities. Time-of-day rates are currently being implemented by many power companies to improve the load factor by encouraging use of electricity during offpeak hours through a substantially lower power charge during these periods as compared with the charge for peak-period use.

Wind-energy systems can provide substantial help in serving these increased loads, and the energy-storage systems used with them to improve economic feasibility can help shift power use to offpeak periods.

The wind-energy water-storage system used in combination with an electric-powered backup heating system, not only can reduce the total required supply of energy, but also allows the backup energy to be supplied during periods when there is reduced power demand, thus helping to improve the load factor and avoiding power use during peak periods. The heat load for the period 6 p.m. to 9 p.m. for the characteristics of the assumed structure for Dec. 1977 to Feb. 1978 with use of Burlington, Iowa, NOAA data are shown in Fig. 7. These data indicate that if, during this heavy power-use period, the energy is supplied from a wind-energy/storage system, the electrical load would be reduced an average of approximately 7 kW. An additional advantage of this heating system is that, because it is not tied to the utility grid, any difficulties of safety or of metering that may arise because of the interconnection are avoided.

A challenging task lies ahead, that of integrating alternative energy sources into electrical power systems to improve the productivity of delivering electric energy and, at the same time, maintaining the system reliability and cost effectiveness. Wind-energy systems are reasonably close to economic feasibility and, because of their characteristics, offer a real potential for reaching this goal.

VI. CONCLUSIONS

Wind-energy systems in the size range of 5-40 kW capacity are capable of supplying a substantial portion of the heating loads of farm structures in many areas of the United States.

This use of wind energy as an alternative energy source can provide substantial benefits to rural power suppliers because peak loads on rural power systems caused by existing and projected electric heating loads can be modified by wind-power systems using energy storage. This can allow serving of increased heating loads on rural power systems in spite of their demand characteristics, which normally may be coincident with electrical system demand peaks.

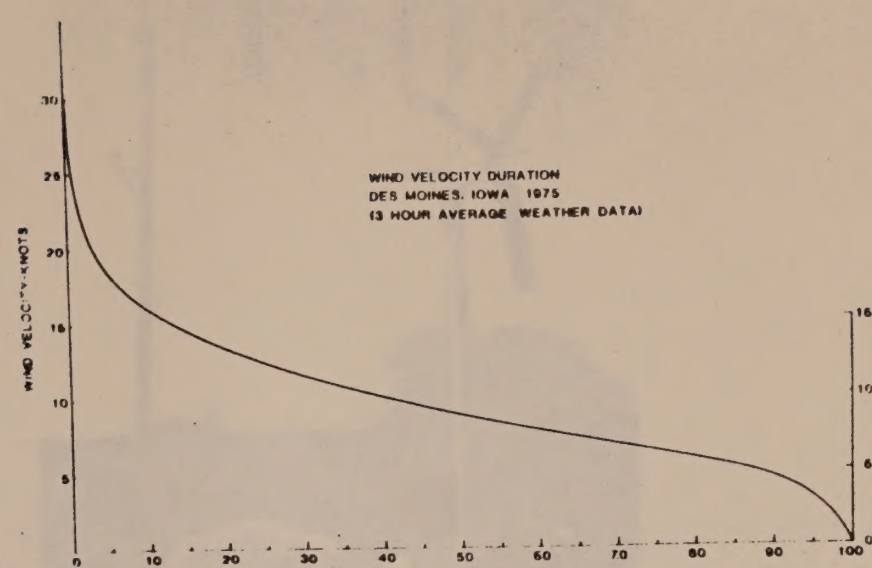


Fig. 1. Wind-speed probability for Des Moines, Iowa, 1975 from NOAA data.

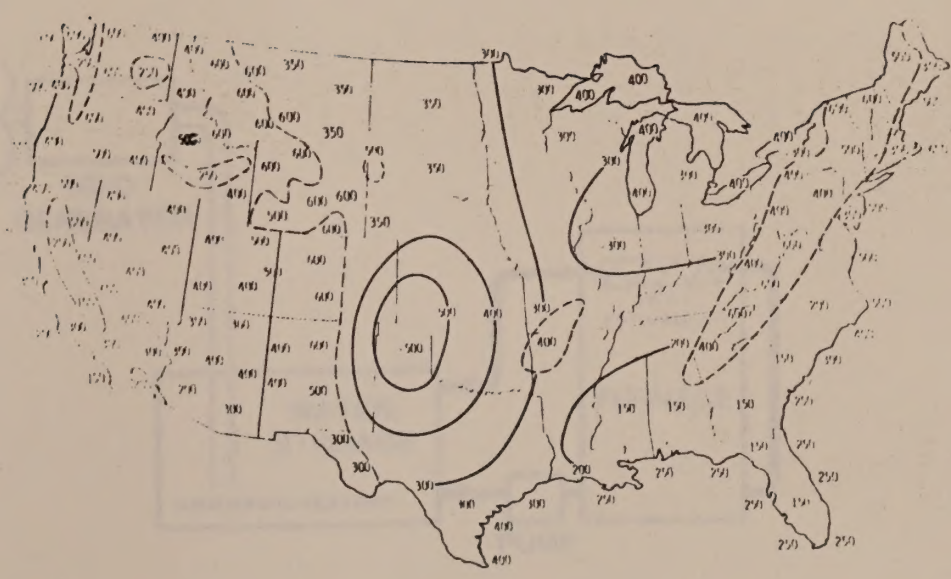


Fig. 2. Winter average wind power (W/m^2) at 50 m above exposed areas.



Fig. 3. Grumman Windstream 25 wind system.

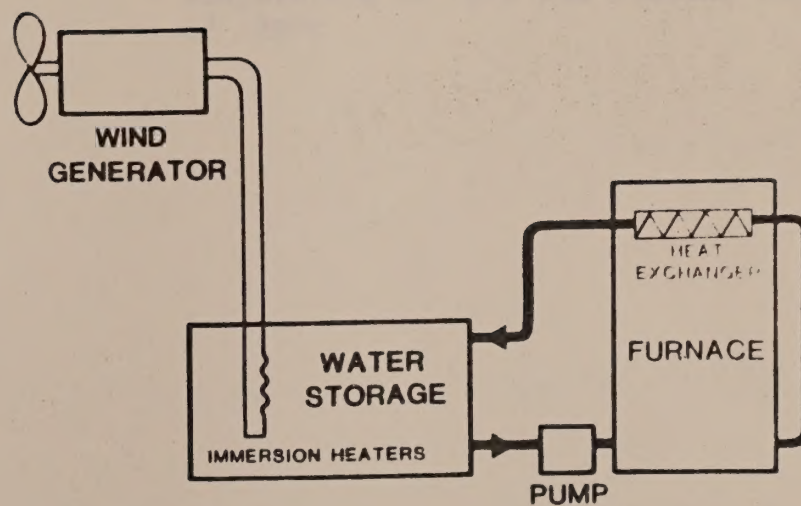


Fig. 4. Wind-energy storage system used for farm structure heating.

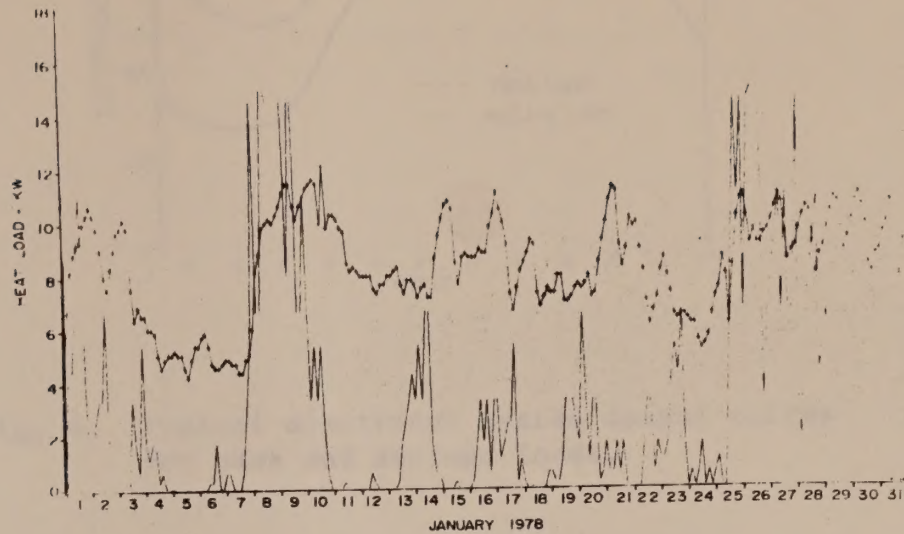


Fig. 5. Heat load and simulated wind system performance of the Grumman Windstream 25 for Burlington, Iowa, Jan. 1978 with use of NOAA data for a 140 m^2 structure with a heat loss of 100 W/m^2 at an inside temperature of 18°C and outside temperature of -29°C .

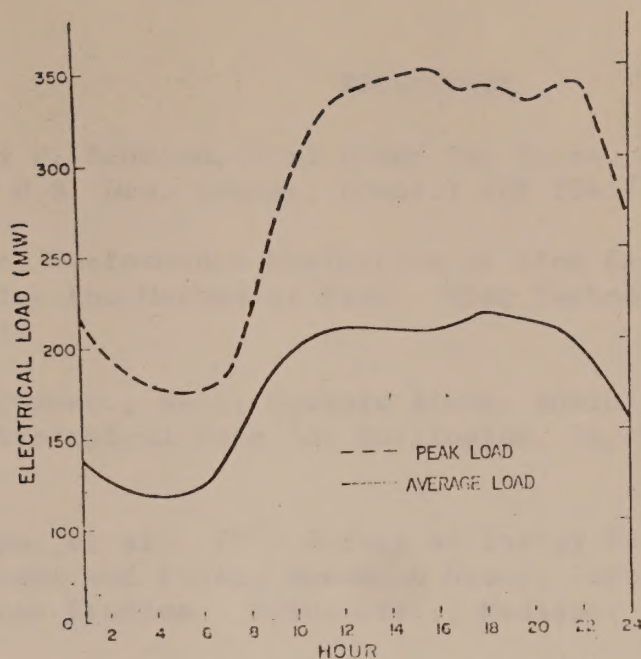


Fig. 6. Typical electrical system demand curves for peak and average loads.

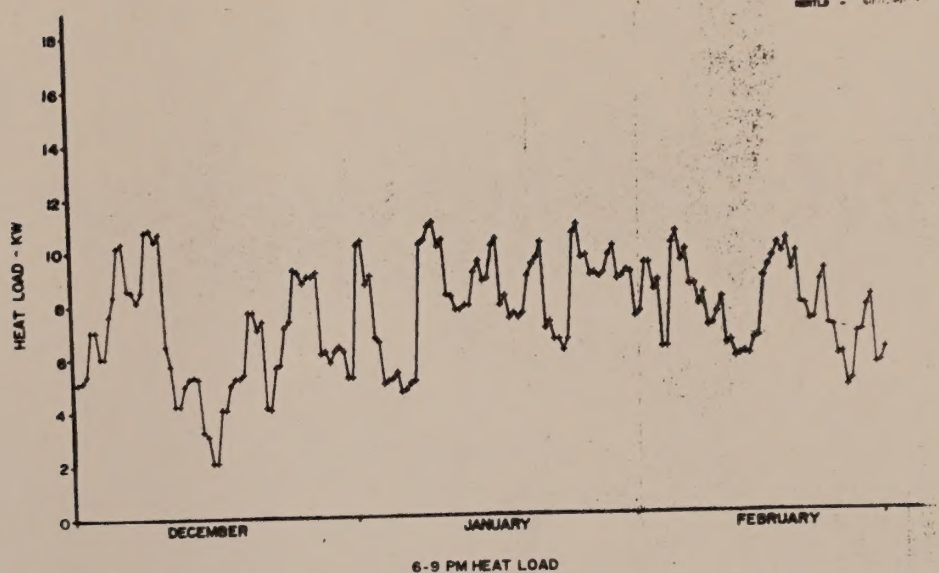


Fig. 7. Heat loads for 6-9 p.m. periods of Dec. 77 to Feb. 78 for a 140 m^2 structure with a heat loss of 100 W/m^2 at an inside temperature of 18°C and an outside temperature of -29°C with use of Burlington, Iowa, NOAA data.

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